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Cumulative Patterns and Controls of Seawall Construction, Thurston County, Washington

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ABSTRACT

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This paper develops and applies techniques to describe and analyze spatial patterns and controls of seawall construction on Puget Sound Lowland shores, Washington State. The main objectives are: (1) to further develop a methodology that statistically differentiates between sequential, clustered, or random patterns of seawall installation; (2) to apply the cumulative pattern assessment methodology to three drift cells in Thurston County that are representative of those typically found along the Puget Sound; and (3) to identify physical and human controls of seawall construction and patterns by analyzing differences for 109 properties in a variety of relevant drift-cell factors, including direction of sediment transport, slope stability, vegetative cover, land use, and property owner experiences and motives. Property-level information was gathered using a combination of on-site field surveys, property assessment records, aerial photograph/map analysis, and property owner questionnaires. The aerial photo analysis showed that shore protection has greatly increased in each drift cell over the last 33–45 years, increasing from 4–15% to 71–83%. Dates of bulkhead installation, as well as the direction and distance of protected sites relative to the first protected sites within each drift cell, were analyzed using a Spearman rank correlation coefficient. Additional statistical analyses did not identify many significant differences in shoreline characteristics or hazard experiences between shoreline reaches that might help explain patterns in seawall installation, with some exceptions, such as differences in shore protection, erosion experiences, and beach types. Similarly, statistical analyses comparing protected and unprotected properties identified few significant differences or associations, primarily related to improved acreage, backshore uses, historic slumping and recent slope failure, and upland/slope vegetation types.

ADDITIONAL INDEX WORDS: *Shore protection, beach erosion, cumulative effects, Puget Sound, Washington State.*

INTRODUCTION

Environmental managers are becoming increasingly aware that many serious environmental problems are created by the cumulative nature of impacts from human development activities, including habitat fragmentation, climate change, and degradation of water quality through nonpoint source pollution (ORIANS, 1995). The term *cumulative impact* often refers to the phenomenon of temporal and spatial accumulation of change in environmental systems in an incremental or interactive manner (SPALING and SMIT, 1995). Cumulative environmental change may originate either from an individual activity that recurs over time and is spatially dispersed or from multiple activities that allow effects to accumulate through spatial or temporal linkages (SONNTAG *et al.,* 1987).

One area that has been increasingly identified as being particularly appropriate for cumulative impact assessment is the coastal zone (GABRIEL and TERICH, 1996). For example, the US Federal Coastal Zone Act Reauthorization Amendments of 1990 require the development and adoption of procedures to assess, consider, and control cumulative and secondary impacts of coastal growth and development, including the collective effects of various individual uses or activities on coastal resources. In response, the National Oceanic and Atmospheric Administration published *Methodologies and Mechanisms for Management of Cumulative Coastal Environmental Impacts* (VESTAL *et al.,* 1995). In a more regional example, a 1991 survey of 200 coastal managers in Washington State identified addressing cumulative and secondary effects of growth as a high-priority issue, with coastal erosion along the Puget Sound being one of the leading concerns (CANNING and SHIPMAN, 1994).

Coastal managers in Washington State are particularly concerned about the cumulative impacts of shoreline protection such as seawalls on sediment supply and transport (SHIPMAN and CANNING, 1993). In response to these concerns, the Washington State Legislature passed *Engrossed Senate Bill 6128,* which amends the Shoreline Management Act to require county governments to have erosion management standards in their shoreline management programs (CANNING and SHIPMAN, 1994). These standards must address both structural (*e.g.,* seawalls) and nonstructural (*e.g.,*

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shoreline setbacks) methods of erosion management, although preference for permitting erosion protection measures is to be given to those "designed to minimize harm to the shoreline's natural environment." In an effort to aid this new approach to coastal erosion management, the Washington Department of Ecology's Shorelands and Coastal Zone Management Program initiated a 3-year Coastal Erosion Management Strategy (CEMS) from 1992 to 1995 (CANNING and SHIPMAN, 1994). Part of the tasks of this study were to begin to characterize shoreline protection trends as well as to develop assessment techniques focusing on the effects of shoreline protection on physical and ecological systems. The CEMS called for study of the nature and the relative severity of the cumulative effects of shoreline protection techniques on physical and ecological resources and processes.

The efforts of the CEMS resulted in several volumes of studies outlining general effects of shoreline protection efforts on physical coastal processes and coastal ecology (*e.g.*, MACDONALD *et al.*, 1994; TERICH, SCHWARTZ, and JOHANNESSEN, 1994; THOM, SHREFFLER, and MACDONALD, 1994) as well as studies on the various engineering and alternative approaches to erosion management (COX, MACDONALD, and RIGERT, 1994; MCCABE and WELLMAN, 1994). These studies have been augmented by several notable academic reviews of seawall impacts (*e.g.*, KRAUS, 1988; KRAUS and MCDOUGAL, 1996; KRAUS and PILKEY, 1988). Although the reviews identify some debate over the specific geomorphic processes responsible for seawall impacts, the majority of the papers reviewed agree with the CEMS studies in attributing to shoreline armoring the following possible cumulative effects: (1) sediment supplies are cut off, leading to beach starvation and transformation of beaches to coarser materials; and (2) the shoreline armoring reflects energy back to the beach, increasing beach scour and the failure of shore protection as footings are exposed (MACDONALD *et al.*, 1994; TERICH, SCHWARTZ, and JOHANNESSEN, 1994).

Interruptions to sediment transport within a drift cell can occur by decreasing erosion rates at the updrift source (*e.g.*, seawalls protecting a glacial bluff toe). Thus, the sediment nourishing these sediment sinks may be locked up in bluffs by seawalls and other forms of shore protection. This is particularly evident along the Puget Sound, where the predominant land use is low-density housing, often located on top of bluffs protected by some form of shoreline protection (usually concrete bulkheads and riprap) (SHIPMAN and CANNING, 1993). Reducing bluff recession rates or restricting net sediment transport leads to sediment starvation and increased erosion downdrift. A negative sediment budget for any length of time will result in steeper nearshore profiles, narrower beaches, and increased erosion (MACDONALD *et al.*, 1994).

Seawalls tend to change a dissipative beach into a reflective beach (ROSENBAUM, 1976), leading to increased reflectivity and beach scour (GRIGGS and TAIT, 1989) and causing beaches to all but disappear (FISCHER, 1986). Loss of beach width may be accelerated by seawalls, because waves hitting the beach rebound off the breakwater and carry sand offshore, gradually narrowing the beach. Seawalls can also increase the intensity of longshore currents, again hastening removal of beach sand. Increased littoral zone turbulence and beach scour leads to a general lowering of the beach profile (DEAN and MAUERMEYER, 1983) and possibly a narrowing of the beach, which may also result from a reduced sediment input due to the presence of the structure (WOOD, 1988).

Several authors caution against making generalizations regarding cumulative impacts of seawalls. TAIT and GRIGGS (1990) have noted that the effects of seawalls are variable because of site-specific controls and processes, including wave climate and permeability of the structure. In another example, KOMAR and MCDOUGAL (1988) note that rip currents produce longshore variability in property losses, masking seawall impacts on the Oregon coast. Similarly, TERICH and SCHWARTZ (1993) have noted that beach profile response to seawalls depends on both sediment supply and the position of the structure relative to the upper berm.

Cumulative impacts also appear to occur on adjacent beaches. SILVESTER (1977) found the presence of seawalls to double the applied littoral energy to the sedimentary bed, leading to increased scour some distance downcoast. A combination of updrift sand impoundment and wave reflection off the end of seawalls can accelerate erosion and scour at downdrift, unarmored beaches. (GRIGGS and TAIT, 1988, 1989). In the Puget Sound region, many shoreline property owners react to incidents of erosion by erecting further erosion control structures. Increased population growth and conversion of vacation cabins to primary residences has accelerated the rate of shoreline protection, leading to public and governmental concern over the effects of shoreline protection on habitat, aesthetics, and rates of downdrift erosion (SHIPMAN and CANNING, 1993).

The purpose of this study was to develop and apply analytical techniques to measure possible cumulative impacts of seawalls by describing and analyzing spatial patterns and controls of seawall construction on Puget Sound Lowland shores. The main objectives were:

(1) to further develop a methodology that identifies the pattern of cumulative impacts of seawall installation, initially differentiating between sequential, clustered, or random patterns;
(2) to apply the cumulative pattern assessment methodology to drift cells representative of those typically found along the Puget Sound; and
(3) to examine cumulative patterns of seawall construction by analyzing site-specific differences in a variety of relevant drift-cell factors, including direction of sediment transport, slope stability, vegetative cover, land use, and property owner motives.

PROCEDURE

Study Sites

The Puget Sound, Washington State's inland coast, contains approximately 3,000 kilometers of coastline, broken into hundreds of discrete drift cells ranging from a few hundred meters to tens of kilometers (SCHWARTZ, WALLACE, and JACOBSEN, 1989). Most of the shoreline consists of bluffs comprised of poorly consolidated glacial sediments, the principal source of sediment for Puget Sound beaches (DOWNING,

Table 1. *Study sites.*

Characteristic	Drift Cell 71 (Nisqually Reach, east of Tolmie State Park; Figure 2)	Drift Cell 50 (Dana Passage, Big Fishtrap and Dickerson Pt.; Figure 3)	Drift Cell 68 (Nisqually Reach, north of Dogfish Bight; Figure 4)
Length of shoreline (km)	1.2	1.9	1.45
Number of parcels	23	45	41
Number of seawalls	1–19 (1953–1998)	3–32 (1965–1998)	6–33 (1953–1998)
Beach characteristics	Mix of fine sand and gravel	Poorly sorted sand, gravel, and cobble	Poorly sorted gravel, cobbles, and boulders
Bluff characteristics	Well vegetated; coastal bluffs up to 30 m high; evidence of instability/landslides	Well vegetated; coastal bluffs up to 20 m high; recent evidence of instability/landslides	Well vegetated; coastal bluffs up to 30 m high; evidence of instability/landslides
Spatial pattern of seawall installation	Sequential	Clustered	Random

1983). Average recession rates of these so-called feeder bluffs are 10 cm/y, though annual rates may be much higher during episodic landslide events (SHIPMAN, 1995). Erosion rates of the bluffs, as well as the beaches, depend primarily on four factors: wave environment, geology, beach characteristics, and human factors such as development and shore protection (TERICH, SCHWARTZ, and JOHANNESSEN, 1994). Sediment is transported from sediment sources along a drift cell to one of many small sediment sinks, including accretion landforms such bay barriers, cuspate forelands, and spits.

Three study sites were chosen for applying the analytical framework developed in this project. The criteria used to choose these sites depended on three main factors: (1) sites that are complete drift cells representative of Puget Sound geomorphic conditions and land uses; (2) sites that represent sequential, clustered, and random patterns of seawall installation; and (3) availability of the baseline data required to apply the cumulative impact assessment methodology. A combination of preliminary research by the authors and previous research (SUSSKIND, 1996) identified three study sites with good historical information of shoreline protection efforts (Table 1, Figure 1). All three sites are in Thurston County, located in the southern region of the Puget Sound Lowland. The principal reason for this is that Thurston County was the first county in Washington State to use a detailed inventory and permitting system of seawall construction, beginning in 1985. Furthermore, its shoreline is representative of geology and land uses found throughout the Puget Sound.

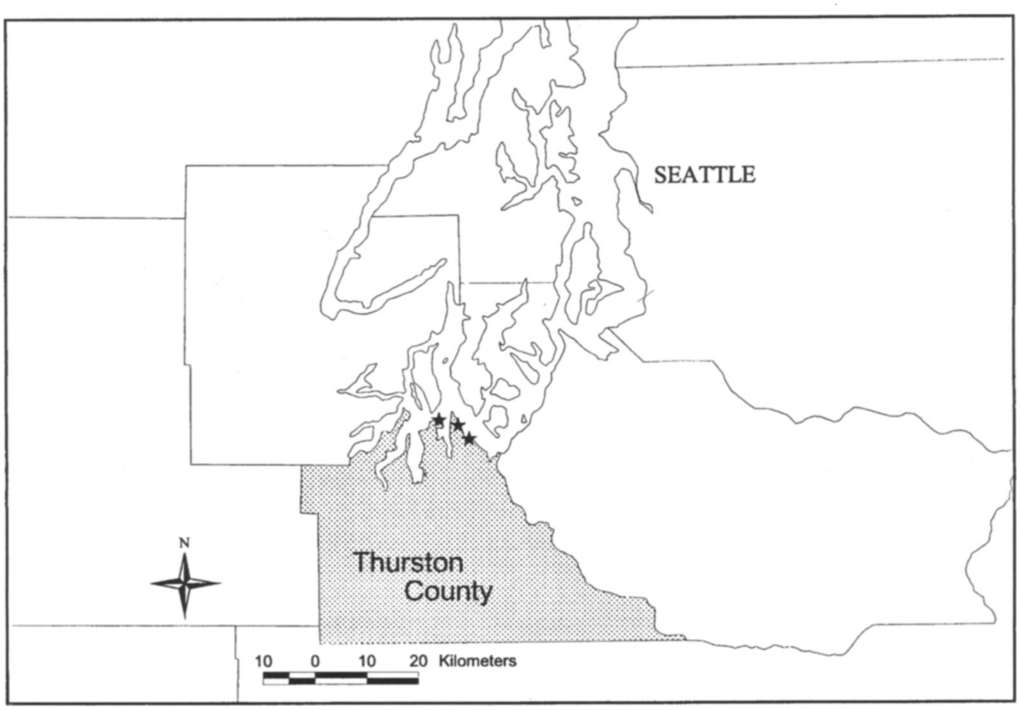

Figure 1. Study site locations, Thurston County, Washington State.

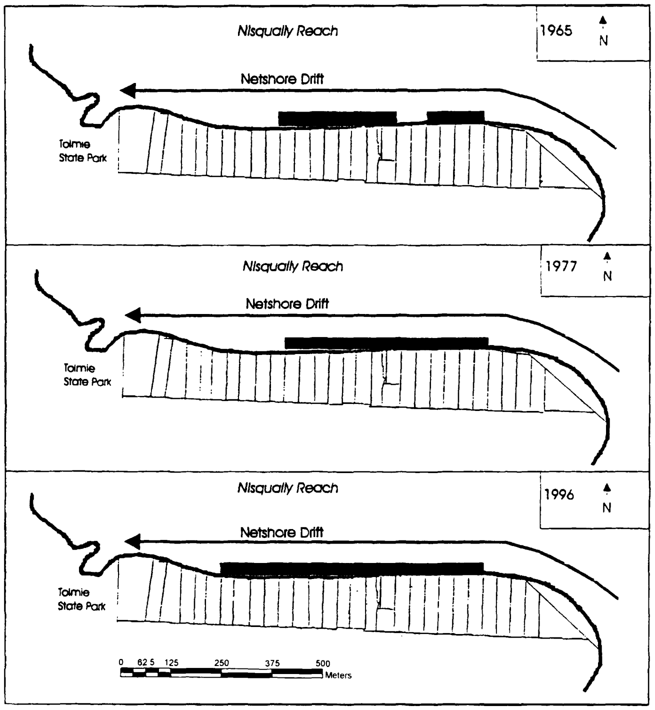

Figure 2. Drift Cell NR71, representing a sequential pattern of shore protection (adapted from Susskind, 1996).

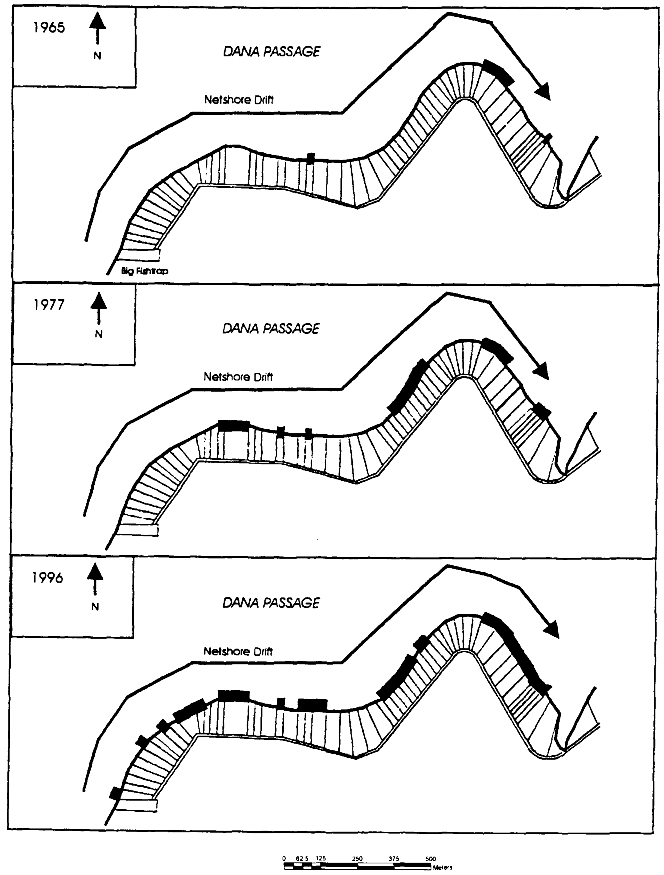

Figure 3. Drift Cell DP50, representing a clustered pattern of shore protection (adapted from Susskind, 1996).

GABRIEL and TERICH (1996) proposed that possible spatial and temporal patterns of cumulative change on the shoreline can be classified as sequential, clustered, or random. In fact, preliminary research by SUSSKIND (1996) provided examples of each type of pattern in the proposed study region. Sequential patterns are characterized by a generally steady, linear progression of seawall construction downdrift, possibly reflecting a cumulative loss of sediment to downdrift areas because of increased shore protection updrift (Figure 2). Clustered patterns are characterized by growth of seawalls around a number of initial nodes of installation (Figure 3). Random patterns show no discernibly organized pattern over time (Figure 4).

Data Collection Methods

Locations, lengths, and construction dates of seawalls were collected on a land parcel basis by accessing Thurston County permit records available from Thurston County Regional Planning, which provided information from 1985 to 1992. This information was taken from SUSSKIND's (1996) master's thesis and corrected for errors. Further use of aerial photographs obtained from the Washington State Department of Ecology augmented this permit information. Use of aerial photographs from several time periods helped determine the location and approximate installation dates of bulkheads for years missing in the permit records (*i.e.,* prior to 1985). Low-altitude aerial photographs at scales of 1 : 12,000 or greater were located through the Washington State Department of Natural Resources, the US Army Corps of Engineers, and Thurston Regional Planning; these were analyzed for 1953–54, 1965, 1970, 1972, 1974, 1976–78, 1981, and 1983. Aerial photo analysis was complicated by several factors, some of which have been identified by other researchers (*e.g.,* MORRISON, KETTMAN, and HAUG, 1993), including: (1) the lack of historical data sets of oblique photographs; (2) aerial photos at too-small scales; (3) vegetation shadowing the shoreline; (4) difficulty in distinguishing drift logs from shore protection; and (5) difficulty in locating parcel boundaries and landmarks, such as tree lines and buildings, over time.

In addition, on-site survey information was gathered for each property (defined as being owned by the same person), including the type of shore protection used and general backshore conditions (*e.g.,* land use, type of vegetative cover, evidence of slope failure, *etc.*). In all, 109 different properties were surveyed. Location of each property in the field was determined through a combination of landmarks from oblique aerial photos; assessor maps; consecutive shoreline measurements using a Bushnell Laser Rangefinder 400 (Bushnell Corporation, Overland Park, Kansas); and field clues, such as buildings, changes in shoreline protection or upland management, and tree lines.

Slope stability and beach/upslope process information was derived using the *Coastal Zone Atlas of Washington: Thurston*

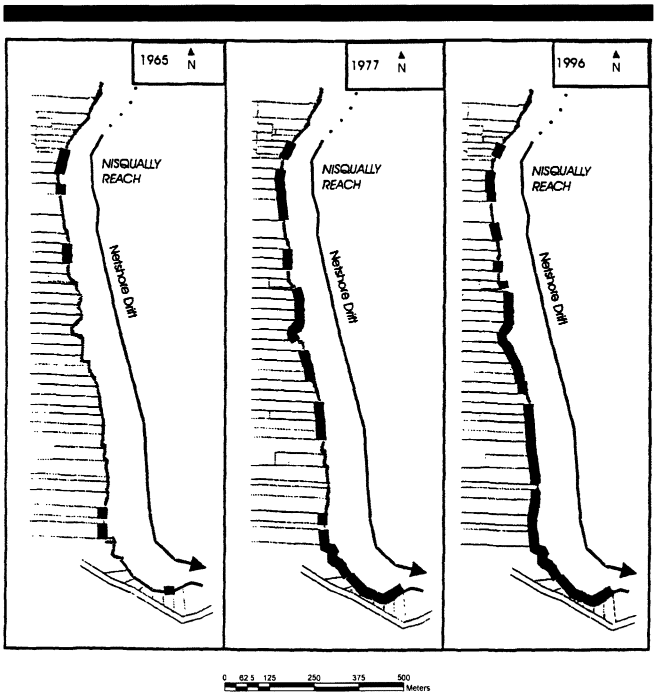

Figure 4. Drift Cell NR68, representing a random pattern of shore protection (adapted from Susskind, 1996).

County (DEPARTMENT OF ECOLOGY, 1977). In addition, because slope vegetation made measuring bluff height with a clinometer impossible in most cases, bluff heights were interpolated from US Geological Survey 1 : 24,000 topographic sheets (Lacey and Longbranch 7.5-Minute Series Quadrangles). The Thurston County Regional Planning Web site provided descriptive data on each property in the study sites, including information on assessed property and building values, property sizes, and amounts of improved/unimproved acreage.

Shoreline setbacks were calculated for each property using geo-referenced 1996 6-inch digital orthos supplied by Thurston County Geodata Center. Plane coordinates (*i.e.,* Universal Transverse Mercator coordinates) were identified for the building closest to the shoreline, as well as the parallel shoreline, using PCI Imageworks V 6.2 (PCI Geomatics, Richmond Hill, Ontario, Canada). After recording the coordinates into the Excel database, ground distances between buildings and the shoreline were calculated using the Pythagorean theorem.

Shoreline property owners along each drift cell were surveyed with a 4-page questionnaire to provide additional information regarding the type and years of seawall installation, as well as the primary motivating factors (*e.g.,* experience of erosion/instability, extension of property, aesthetics, pressure by overzealous contractors or neighbors, *etc.*). Such a method of inquiry has a long tradition in hazard research, focusing on the perception of erosion hazards, causes, and adjustments (*e.g.,* MITCHELL, 1974). A number of different questionnaires were collected through a literature search and personal contacts, which were used to help develop a comparable survey tool (*e.g.,* DILLEY and RASID, 1990; ENVIRONMENT CANADA, 1990).

Data were collected using a mail survey approach, which is increasingly promoted for geographic and hazards research (FEITELSON, 1991). The mail survey followed an approach modified from a procedure outlined by DILLMAN (1978) that has been applied successfully in hazard research (*e.g.,* CROSS, 1990). In this study, of the 109 surveys that were distributed, 4 were returned unopened because of either outdated addresses, recent changes of ownership, or recent deaths of former owners. Of the 105 surveys that were received by shoreline owners, 68 were completed and returned, for a response rate of 65%.

Data Analysis

Although cumulative patterns of shore protection have been described qualitatively (GABRIEL and TERICH, 1996), this research applied an alternative statistical technique to nearest-neighbor analysis to distinguish patterns of cumulative change. Nearest-neighbor analysis, a common statistical technique for determining the spatial arrangement of point patterns, is not appropriate for this type of assessment. The method calculates only the degree and type of dispersion (*e.g.,* random, clustered) and is unable to distinguish sequential patterns. In addition, attempts to apply nearest-neighbor analysis to preliminary data resulted in inappropriately high index values, reflecting the difficulty in calculating density along a linear feature. Consequently, dates of installation, as well as the distance of protected sites relative to the start of each drift cell, were analyzed using a Spearman rank correlation coefficient. It was expected that drift cells showing a sequential, downdrift pattern of seawall installation would have high correlation coefficients (*i.e.,* successive years of seawall installation will occur at greater distances downdrift from the first set of installations at the beginning of the drift cell). Conversely, random patterns were expected to have very low correlation coefficients, whereas clustered patterns were expected to have moderate coefficient values, because successive seawalls are constructed downdrift from several different initial nodes. Use of this statistical analysis requires more disaggregated time-series of data points than provided by the 3 years of data gathered through previous research (SUSSKIND, 1996), especially for the years not covered in the Thurston County permit record (*i.e.,* between the years 1965 and 1985). (*Note:* Although 1965 was initially used as a starting point for the study, earlier aerial photographs were needed to develop more data points for Drift Cell 71, because 13 out of 23 parcels already had shore protection by 1965.)

In a separate statistical analysis, both sequential and nonsequential patterns were analyzed relative to the on-site survey information and questionnaire responses, including general backshore characteristics and various property owner motives. The on-site survey information, questionnaire responses, and permit file information from Thurston County were statistically analyzed in order to determine similarities or differences in property characteristics and response patterns between property owners as well as study sites. This analysis tried to determine possible differences in factors between properties that either have seawalls or not, as well as to determine possible differences in factors between the three sites, each representing a certain cumulative pattern of seawall installation. This analysis primarily used the chi-square test to analyze the on-site survey and questionnaire data, which principally produced nominal or weakly ordinal scale data (*e.g.,* land use and building types, vegetation type, type of erosion damage experienced). Other difference tests were used if the data allowed, including the parametric difference of means test, the Mann-Whitney U test, and the Kruskal-Wallis test. Only significant results ($p < 0.05$) are reported.

RESULTS

Drift Cell and Shoreline Property Characteristics

Cumulative Pattern of Seawall Construction

The aerial photo analysis showed that shore protection structures have proliferated in each drift cell over the last 33–45 years (Table 1). Between 1953 and 1998, the percentage of protected properties increased from 4% to 83% in NR 71, and from 15% to 80% in NR 68 during the same time period. In DP 50, the proportion of protected properties increased from 7% in 1965 to 71% in 1998.

The use of Spearman rank correlation analysis to quantify patterns of shoreline protection by comparing dates of installation and distance from the start of a drift cell was fairly successful. The Spearman rank coefficient for NR 68, identified as having a random pattern of shore protection, is −0.11, while the Spearman rank coefficient for NR 71 is 0.28, a consistent though somewhat weak value for a sequential spatial pattern of seawall construction. The Spearman rank coefficient for DP 50 was somewhat perplexing at −0.66, which might be consistent with a clustered pattern, though also represents a strongly inverse relationship that indicates the installation of shore protection tended to occur in an updrift direction, opposite of what one might expect due to downdrift sediment starvation.

Property Owner Profile

The spatial distribution and other characteristics of the respondents to the questionnaire can be found in Table 2. The number of shoreline properties in each shoreline reach is fairly proportionally represented by the sample.

Respondents were asked why they had purchased their property. Of the variety of possible reasons identified, the proximity to water (94%), the beauty of the location (88%), and the recreational possibilities (60%) were the most popular reasons chosen. Approximately 81% of the respondents use their property as a year-round home, whereas another 13% use their property as a cottage or second home. When asked about their satisfaction with their property, an overwhelming number (88%) felt that most of their expectations had been met.

In terms of length of ownership, 50% of the respondents stated that they had owned their cottage for more than 15 years, with 30% having owned their properties for more than 25 years. As noted by SCOTT and PARKER (1996), property owners with such long-term ownership represent reliable sources of information, because they can provide continuous histories of shoreline erosion and the nature of adjustments they have adopted.

Table 2. *Property owner profile.*

Property Owner Characteristics	Total (% of respondents)
Location of respondents	
Nisqually Reach 71	21
Nisqually Reach 68	32
Dana Passage 50	47
Reasons for purchase	
Proximity to water	94
Beauty of the location	88
Recreational possibilities	60
Investment potential	40
Retirement	25
Local community	19
Other	10
Length of family ownership/management	
Less than 5 y	12
5–10 y	7
11–15 y	7
16–20 y	10
21–25 y	10
over 25 y	53
Primary use of the property	
Year-round home	81
Cottage or second home	13
Other (*e.g.,* business and home)	6
Satisfaction with property	
Most expectations have been met	88
Some expectations have been met	6
Most expectations have not been met	3
No expectations have been met	1.5
Don't know	1.5

Shoreline Property Profile

The characteristics of the shoreline properties can be found in Table 3. According to the survey results, 99% of the shoreline properties have buildings, predominantly classified as residential (97%), the majority of these being single-family dwellings used as principal residences by the owner (91%). Building setbacks from the shoreline average 117 meters, though ranging between 6 and 432 meters. The average property size is 1.45 acres, although individual properties range in size from 0.29 to 5.7 acres. The proportion of improved and unimproved land, as identified by the Thurston County Assessor's records, also varies greatly between properties, though the amount of unimproved land tends to be higher. The median and range of property, land, and building values can also be found in Table 3, again reflecting great variability as well as the higher values associated with shoreline property.

Shoreline Property Bluff and Beach Characteristics

The bluff heights measured through the field survey averaged about 18 meters in height, ranging from 0 to 30 me-

Table 3. *Shoreline property profile.*

Property Characteristic	Total
Location of property (%)	
Nisqually Reach 71	23
Nisqually Reach 68	41
Dana Passage 50	45
Buildings present on property (%)	99
Principal type of buildings on property (%)	
Single-family home	91
Mobile home	4
Other	5
Building setback (m)	
Mean	117
Range	6–432
Type of land use (%)	
Residential	97
Vacant	2
Other	1
Property size (acres)	
Mean	1.45
Range	0.29–5.7
Proportion of improved and unimproved land (acres)	
Improved	
Mean	0.65
Range	0–2.6
Unimproved	
Mean	0.80
Range	0–5.2
Market values of total property ($1997)	
Median	210,000
Range	39,600–473,300
Market values of land ($1997)	
Median	122,200
Range	39,400–473,300
Market values of building ($1997)	
Median	71,900
Range	200–288,100

Table 4. *Shoreline property bluff and beach characteristics.*

Bluff/Beach Characteristic	Total
Bluff height (m)	
Mean	18
Range	0–30
Slope stability (%)	
Unstable	77
Intermediate	15
Stable	8
Historic evidence of slope failure (%)	
Slumping	59
Gullying	3
Recent evidence of slope failure (%)	
Slumping	32
Wave undercutting	26
Rilling	8
Gullying	1
Upland vegetation (%)	
Residential lawn/garden	86
Mixed trees	50
Coniferous trees	16
Deciduous trees	5
Shrub	5
Slope vegetation (%)	
Shrub	57
Mixed trees	37
Deciduous trees	32
Grassland	16
Residential lawn/garden	8
Coniferous trees	2
Type of beach (%)	
Mixed-medium material	62
Sand	18
Fine mixed material	14
Sand/silt/clay	5
Exposed platform	1

ters (Table 4). Many of the bluffs in the three reaches were classified as unstable by the *Coastal Zone Atlas* (DEPARTMENT OF ECOLOGY, 1977), although only 35% were classified as feeding, because of the prevalence of bulkheads already by 1977 (60% of properties). The data from the field survey confirm the dynamic nature of the bluffs in this region. The survey found historic evidence of slumping in 59% of the properties, as well as more recent evidence of slope failure, primarily in the form of slumping (32%) and wave undercutting (26%).

The type of upland vegetation on top of the bluffs is mostly residential lawn and garden (86%), although this vegetation type could also often be found in conjunction with mixed forest or coniferous trees. Slope vegetation tends to be dominated by shrubs (57%) because of extensive clearing of forest vegetation, although mixed forest (37%) and deciduous trees (32%) are also common. The field survey found the beach types to be dominated by mixed-medium material (62%), and the *Coastal Zone Atlas* (DEPARTMENT OF ECOLOGY, 1977) noted that most of the beach processes have either been modified (60%) or show evidence of erosion (34%).

Erosion Experience, Damages, and Causes

According to the results of the mail survey, 67% of properties in the three reaches have experienced erosion (Table 5). Of those experiencing erosion, 75% of the respondents stated that they had been aware of the potential for erosion when they bought their property. Property damage related to erosion predominantly affects steps leading down to the beach (reported by 32% of respondents), followed by damage to lawns and gardens (21%) and shore protection (18%). Another 56% of respondents noted erosion damage occurring to their neighbors' property. Shoreline owners were also asked to identify the principal causes of erosion affecting their property. The majority of those experiencing erosion (53%) identified slope instability as being among the top three causes of the hazard, whereas a further 24–33% identified high water levels or storm/wave action as one of the principal causes. Of those experiencing erosion, the majority (62%) felt that the erosion would have either no or a small effect on the sale price or ease of sale of their property. Despite the predomi-

Table 5. *Erosion experience and causes.*

	Total
Properties experiencing erosion*	67
Awareness of erosion potential†	75
Type of erosion damage (% of respondents)	
Steps to beach	32
Lawns and gardens	21
Shore protection	18
Beach	12
Your dwelling unit	7
Boat launch facilities	4
Road	4
Pier or dock	3
Other buildings	3
Erosion damage to neighbor's property*	56
Effect of erosion on sales price or ease of sale†	
No effect	33
Very small effect	29
Moderate effect	17
Large effect	22
Principal causes of erosion†	
Slope instability/landslides	73
Storm/wave action	33
High water levels	24
Neighbor's shore protection structure	9
Loss of beach width	7
Shore protection on your property	4
Lowering of beach	2
Actions of nearby property owner	1
Other	1
Evidence of long-term changes*	
No evidence	66
Bluff erosion	9
Lowering of beach	8
Shoreline erosion	8
Beach building up	6
Other	3

* % of respondents.
† % of those respondents experiencing erosion.

Table 6. *Shore protection characteristics.*

Shore Protection Characteristics	Total
Properties having shore protection devices*	72
Shore protection type†	
Concrete bulkhead	52
Log bulkhead	13
Logs	13
Wooden plank bulkhead	7
Rock bulkhead	6
Post bulkhead	4
Other	5
Shore protection height (midpoint in m)	
Mean	1.4
Range	0.2–2.7
Evidence of back-filling†	73
Reasons for shore protection installation‡	
Protect property	65
Experience of landslides/slope instability	34
Experience of beach erosion	26
Improve property value	25
Neighbor installed shore protection	21
Aesthetics	16
Environmental benefits	16
Advertising or approached by contractors	11
Extension of property	9
Backshore use*	
Vegetation	49
Storage (boat, *etc.*)	34
Boat launching	14
Picnic/patio area	14
Lawn	14
Boathouse	9
House	6
Firepit	5
Other	2
Reasons for choice of shore protection type‡	
Personal experience/design	38
Contractor's advice	16
Consultant's advice	16
Compatibility with neighbor's shoreline structure	16
Advice from government agency	12
Alternative erosion management practices‡	
Drainage diversion	41
Leaving natural vegetation	37
Slope grading	6
Other	3

* % of properties.
† % of properties with shore protection.
‡ % of respondents.

nance of the erosion hazard, the effects seem to be either short term, sporadic, or imperceptible over time, because 66% of the respondents reported no evidence of long-term change to their shoreline.

Seawall Construction

As one might expect with the relatively high erosion experience, the field survey found 72% of the properties to have some form of shore protection devices (Table 6). Of the properties with shore protection, concrete bulkheads were the predominant type (52% of protected properties), while 73% also had evidence of back-filling. The relative proportions of different types of shore protection are consistent with those reported for Thurston County (MORRISON *et al.*, 1993) and the Puget Sound as a whole (TERICH, 1989). Backshore uses are dominated by vegetation (49%) and storage for boats and firewood (34%), though boat launches, picnic/patio areas, and lawns are also fairly common uses (14% each).

When asked by the mail questionnaire to identify reasons why they had installed shore protection, the majority of respondents noted protection of property (65%) as one of the primary reasons. Other popular answers included the experience of landslides/slope instability (34%) or beach erosion (26%), as well as to improve property values (25%). In terms of the choice of shore protection type, the majority of respondents (38%) noted the importance of personal experience rather than a contractor's or consultant's advice (16% each), compatibility with a neighbor's shoreline structure (16%), or advice from a government agency (12%). The mail survey also found the use of alternative erosion management practices to be less prevalent. For example, 41% of the respondents used

Table 7. *Shoreline property profile (by reach).*

Property Characteristic	Dana Passage 50	Nisqually Reach 68	Nisqually Reach 71
Type of beach*			
Mixed-medium material	30	94	0
Sand	35	0	0
Fine mixed material	22	6	100
Sand/silt/clay	14	0	0
Exposed platform	4	0	0
Erosion experience†	83	55	50
Shore protection type‡			
Concrete bulkhead	20	68	75
Log bulkhead	13	9	20
Logs	3	6	0
Wooden plank bulkhead	3	12	5
Rock bulkhead	17	0	0
Post bulkhead	36	0	0
Other	7	6	0

* % of properties.
† % of respondents.
‡ % of properties having shore protection.

drainage diversions while 37% leave natural vegetation in place.

DISCUSSION

While the use of Spearman rank correlation analysis to quantify and differentiate patterns of shoreline protection proved to be successful in differentiating sequential, clustered, and random patterns, further statistical analyses were conducted to determine additional differences in property characteristics and response patterns between study sites, each representing a specific cumulative pattern of seawall installation, as well as to determine possible differences in factors between protected and unprotected properties. We had hoped that such tests would help explain differing patterns in seawall installation, as well as indicate the relative importance of various possible physical and cultural controls. Unfortunately, these tests did not identify many significant differences in shoreline characteristics or hazard experiences, either between shoreline reaches or between protected and unprotected properties, that might help shed light on the primary controls of seawall installation.

Chi-square analysis showed relevant reach characteristics to be remarkably similar, the exceptions being differences in shore protection types, erosion experiences, and beach types (Table 7).The greater variation in beach types and shore protection devices, as well as greater beach erosion experience, might account for the more clustered pattern of shore protection found in the DP 50 reach. Similarly, Mann-Whitney U tests and chi-square tests of differences between protected and unprotected properties identified few significant relationships. For example, the only significant Mann-Whitney U test result identified a higher amount of improved acreage in protected properties (median − 0.6 acres) than unprotected properties (median − 0.5 acres), much as one would expect. However, no significant differences were found for other potentially relevant variables, such as expecting significantly higher land and building values, smaller property sizes, shorter setback distances, or higher bluff heights to be associated with protected properties.

The analysis did find that many backshore uses and resulting damage types were found either entirely or predominantly with protected properties (Table 8). The need to develop and protect these backshore uses may be one of the primary motivations for seawall construction in the study area. In addition, while 40% of owners of protected properties noted that they leave natural vegetation as an alternate erosion strategy, the field survey found that both upland vegetation and slope vegetation tends to be different on protected and unprotected properties. For example, upland vegetation on protected properties tends to have a higher amount of residential lawns/gardens and shrubs, with fewer coniferous and deciduous trees. Similarly, slope vegetation on protected properties tends to be more grassland and residential lawns/gardens, with fewer deciduous trees and shrubs than on unprotected properties. Both differences in upland and slope vegetation seem to indicate clearing of vegetation, whether to accommodate views or backshore uses, tend to be more common on protected properties. However, linking these differences in vegetation types and management to greater susceptibility to erosion and seawall construction is complicated by the fact that a higher proportion of unprotected properties actually showed historic evidence of slumping (74%), as well as evidence of recent slope failure, especially wave undercutting (70%) and slumping (52%). Obviously these types of erosive events tend to be reduced on properties currently protected by seawalls.

This study was not able to support the assumption that seawall construction is strongly linked to geomorphic controls and differences in the intensity of shoreline erosion, where more rapidly eroding properties are protected first and resulting downdrift impacts lead to further seawall installation. Patterns of seawall construction seem to be obfuscated by a wide variety of other possible controls, including the physical characteristics and uses of shoreline properties, as well as

Table 8. *Shoreline property bluff and beach characteristics for protected and unprotected properties.*

Property Characteristic	% of Protected Properties	% of Unprotected Properties
Backshore use		
Storage (boat, *etc.*)	44	4
Vegetation	36	96
Boat launching	19	0
Picnic/patio area	19	0
Lawn	18	0
Boathouse	12	0
House	8	0
Firepit	6	0
Other	2	0
Alternative erosion management (as % of respondents)		
Drainage diversion	42	38
Leaving natural vegetation	40	46
Slope grading	9	0
Other	2	8
None	26	38
Type of erosion damage (as % of respondents)		
Steps to beach	30	46
Lawns and gardens	23	0
Shore protection	19	0
Beach	13	8
Your dwelling unit	8	0
Road	6	0
Boat launch facilities	4	8
Pier or dock	4	0
Other buildings	3	0
Historic evidence of slope failure		
Slumping	55	74
Gullying	2	4
Recent evidence of slope failure		
Slumping	25	52
Wave undercutting	14	70
Rilling	6	17
Gullying	1	0
Upland vegetation		
Residential lawn/garden	87	78
Mixed trees	49	43
Coniferous trees	13	30
Shrub	6	0
Deciduous trees	5	9
Slope vegetation		
Shrub	55	74
Mixed trees	37	26
Deciduous trees	29	52
Grass	19	9
Residential lawn/garden	11	0
Coniferous trees	1	4

property owner motivations and perceptions of erosion risk. It is hoped that further application of the spatial analysis introduced in this study to larger samples and other regions may assist in understanding the cumulative patterns of seawall construction and their underlying physical and cultural controls.

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